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Integrated Compartment-Machine Design for Low-Coal Shuttle Cars

By John R. Bartels, August J. Kwitowski,
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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	pct	percent
h	hour	yr	year
in	inch		

INTEGRATED COMPARTMENT-MACHINE DESIGN FOR LOW-COAL SHUTTLE CARS

By John R. Bartels,[1] August J. Kwitowski,[1] and William D. Mayercheck[2]

ABSTRACT

This Bureau of Mines report describes the development of a preliminary design for a novel, protected, cab-shuttle car for use in working seam heights down to 40 in. Because of the severe restrictions imposed by low-coal operation, Mine Safety and Health Administration (MSHA) regulations only require canopy protection on shuttle cars operating in seam heights of 42 in or greater. MSHA routinely grants variances for canopy use in seams 48 in high or less. The design was generated by giving the operator needs equal priority as related to machine performance parameters. Cab-shuttle car concepts that led to the recommended design are described, along with criteria and testing used to evaluate their potential effectiveness.

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INTRODUCTION

Cabs and canopies installed on underground coal mining face equipment in use on high-coal equipment have established an impressive record of preventing fatal and nonfatal operator injuries. MSHA estimates that from January 1974 through December 1985, the protective structures kept 233 lives from being lost as a result of roof falls (*2*).[3] Unfortunately, the successful application of cabs and canopies has occurred almost exclusively in relatively high coal seams. A 1982 survey showed that for working heights below 48 in, only 27 pct of all face equipment had protective operator structures. For working heights below 42 in, the percentage of equipment with cabs and canopies dropped to 2 pct (*3*).

While the availability of protection in working heights below 48 in is low, the need for protection is high. For the 2 yr period 1980 through 1981, there were a total of 2,212 fatal and nonfatal equipment accidents in working heights below 48 in. It was estimated that 71 pct of these accidents could have been prevented had protective structures been employed (*3*).

A problem with trying to provide workable cabs and canopies for face equipment used in seam heights below 48 in relates to simple geometry. Insufficient space exists to (1) have the machine perform its intended functions, (2) station an operator and the controls, (3) insure adequate operator vision to key points on the machine and in the mine, (4) provide sufficient operator comfort for protracted work periods, and (5) provide structures that both protect the operator and do not significantly interfere with other requirements. The issue of protecting shuttle car operators from hazards becomes increasingly difficult with decreasing working height.

Underground face equipment, such as continuous miners, roof bolters, face drills, etc., is usually much easier to equip with protective operator cabs than shuttle cars. These types of face equipment perform their functions primarily at one location; e.g., a continuous miner extracts coal at the face, while, because of its function, a shuttle car frequently travels through the working section. The tram rates of shuttle cars are also significantly higher than those of other face equipment. Current shuttle car designs tend to maximize tram clearances for tight spots in mine workings.

The requirement for tram clearance is opposed by a primary goal in the shuttle car design – maximize the amount of cut coal transported from the face. An unfortunate effect is that space that should be used for operator, the controls, and a protective structure is sacrificed for increased coal capacity and tram clearance. Classic shuttle car design philosophy has provided for operator needs as a secondary consideration, which partially explains the limited success achieved over decades in developing adequate protective cabs for thin-seam shuttle cars.

PROJECT EXECUTION

The failure of past design methods to produce adequate thin-seam shuttle car cabs required that a fresh approach be taken. Thus, the objective of this project was to develop an acceptable cab-shuttle car design by giving the operator's needs equal priority as related to classic design criteria. Although the resulting design could have diminished performance specifications compared with present designs, a suitable compromise was achieved among operator safety, coal-carrying capacity, and maneuverability.

A wide variety of ideas and influences were considered to generate cab-shuttle car concepts and guide the progression of the project. Therefore, a project advisory committee was formed of Bureau and MSHA personnel. MSHA participation ensured contributions to the project and updated the agency on developments of interest.

The advisory committee functions were to formulate criteria for evaluating the acceptability of cab-shuttle car concepts; conceive cab-shuttle car concepts; evaluate, refine, and eliminate concepts; and make recommendations for future project efforts.

EVALUATION CRITERIA

An initial task was the formulation of criteria for gauging the acceptability of cab-shuttle car concepts. Two classes of criteria were developed: those considered mandatory--not meeting them would cause a concept to be rejected outright; and those considered desirable--concepts including them would be ranked higher than those that did not.

Mandatory criteria were

1. The cab should employ protective operator structures; this includes protection from ground falls and the minimization of pinching and squeezing-type accidents, which are the most common in thin-seam shuttle car haulage (*3*).

2. The cab-shuttle car should be maneuverable in workings having typical dimensions for thin-seam room-and-pillar mining.

[3] Italic numbers in parentheses refer to items in the list of references at the end of this report.

3. The operator should have adequate field of vision to key points on the machine and in the mine.

4. The operator should be provided a comfortable working position.

5. Other section workers should not be endangered by haulage vehicle operation.

6. Cab ingress and egress should be reasonable.

7. The cab-shuttle car should be usable in working heights down to 40 in.

The decision was made to target a 40-in working height for the cab-shuttle car design, based on the following factors:

A. For the development to be viewed as significant, it should be applicable below the current 42-in limit where Federal regulations mandate cabs and canopies.

B. Present industry practice considers 36-in working heights as the low cutoff point for batch-type haulage; lower height mines generally use continuous haulage.

C. Previous studies showed a general dislike for low-height operating positions other than the semireclined, which is usable down to about 40 in for high-speed face equipment (*4*).

D. The development effort could be approached with a reasonable degree of confidence for a successful outcome.

Desirable criteria included

1. Ideally the operator should not be required to change seat positions depending upon the travel direction. In low working heights, changing seats is currently the only successful method of obtaining vision in both travel directions. However, the procedure is cumbersome, awkward, time consuming, and exposes the operator to additional hazards.

2. Cab concepts should be as compatible as possible with commercially available shuttle cars.

3. Cab concepts should be adaptable to haulage vehicles other than shuttle cars.

4. Electronic sensory aids should be employed, but kept as simple as possible. For example, a closed-circuit television system (CCTS) could provide information on blind spots not within the operator's line of sight.

5. The operator should be provided an indication of obstacles in the vehicle path.

6. For cab designs where it is necessary for the operator to change seat positions according to the travel direction, the controls should be miniaturized to the point of being a hand-held module. The module should be connected to machine actuators through either a tethered or radio remote control link. This would eliminate the need for two separate control panels.

7. The resulting design should be cost effective.

8. The controls and cab layout should give the operator a feeling of confidence, allow easy operation, and provide a natural control sequence.

9. The complexity of the design should be minimized to reduce maintenance frequency.

10. Floating cabs should be utilized. Past Bureau projects (*1, 3-4*) indicated that floating cabs generally provide more operator space than traditional fixed cabs.

CAB-SHUTTLE CAR CONCEPTS

Cab-shuttle car concepts were generated at monthly meetings held by the advisory committee, and were quickly critiqued through open discussions. Those concepts that survived the oral discussion stage were translated into sketches and/or scale drawings. Most drawings referenced concepts to the outline of a National Mine Service[4] model MC28 shuttle car in a typical 40-in working height entry; this was considered typical of the 1,839 shuttle cars currently in use in coal seams under 48 in. At subsequent meetings, the concepts underwent further evaluation, discussion, and refinement. Many concepts were eliminated through this process; other new ideas were conceived and entered the system.

The generated concepts fell into five general cab-shuttle car configuration:

[4]Reference to specific products does not imply endorsement by the Bureau of Mines.

1. Traverse, center-driven cab: The operator cab is situated perpendicular to the longitudinal axis of the haulage vehicle, midway between its ends. An advantage is that the operator would not have to change seat positions when the travel direction changes. Disadvantages include that the cab would decrease the coal-carrying capacity and the operator would not have excellent field of vision in either direction of travel.

2. Parallel, end-driven cab: The operator cab is situated parallel to the longitudinal axis of the haulage vehicle, close to one end of the machine. Assuming the operator changes seat positions depending on travel direction, this configuration would provide the operator with very good direct vision in one travel direction, but poor direct vision in the opposite direction. Assuming the operator remains in one seat position for both travel directions an

automated steering system or the ability to steer the vehicle from sensory input devices would be required.

3. Parallel, center-driven cab: The operator cab is situated parallel to the longitudinal axis of the haulage vehicle, midway between its ends. Assuming that the operator changes seat positions with travel direction and the cab width could be approximately 10 in greater than a standard cab, visibility along the side of the machine could be adequate, but somewhat impeded by machinery in the field of view. When considering a design where the operator sits in only one position, direct visibility in one travel direction would be nonexistent, requiring the addition of remote sensory and/or automated steering systems.

4. Transverse, end-driven cab: The operator cab is positioned at an end of the vehicle, perpendicular to the longitudinal axis of the machine. An advantage is that the operator would have extremely good field of vision when tramming to the dump site and restricted, but adequate, field of vision in the opposite tram direction. Perceived problems included a significant loss of coal-carrying capacity, potential roofing-out problems, and the cab and chain conveyor mechanism competing for the same space.

5. Cross-car, end-mounted cab: The operator is positioned across the end of the vehicle, perpendicular to the longitudinal axis of the chain conveyor. This arrangement would give the operator unobstructed vision when tramming to the dump site and very good vision down the empty conveyor when tramming to the face. The main disadvantage appeared to be increased complexity of operation when unloading coal.

DETERMINATION OF REMOTE VISION LIMITATIONS

The committee initially considered cab-shuttle car concepts using conventional parallel, center-driven and parallel, end-driven cab placements. Exploration of these concepts readily revealed a primary objection to the use of protective cabs in low coal – the problem of direct operator vision to key reference points.

If the desirable feature of maintaining the operator in one seat position is assumed, both versions of parallel cabs considered do not allow the operator direct vision in one travel direction. A simple CCTS was proposed to provide the operator with visual input from the blind travel direction.

A quick experiment was conducted to estimate an operator's ability to steer a vehicle using only CCTS vision. The experiment utilized available closed-circuit video equipment and a battery-powered vehicle; it took place on vacant roadways at the Bureau's Pittsburgh (PA) Research Center. A camera transmitted a forward view, in the travel direction, to a video monitor placed in front of the driver. A shroud prevented direct forward vision. Five different drivers attempted to negotiate straight and curved road sections using only visual information from the monitor. The results of the experiment were not favorable. The consensus was that satisfactory movement in a desired path required great concentration and could be achieved only if an object was present to sight along, such as a curb. Poor performance using the video system was attributed to the lack of depth perception and differences in field and angle of view between a person's eyes and the camera lens.

This experiment was conducted with the drivers trying to maneuver the vehicle while facing the travel direction. For the concept to be usable with the cabs, the operator would need to maneuver the vehicle while facing in the direction opposite of travel, further decreasing the likelihood of success.

The negative experiment results led to the following conclusions on design options related to parallel-oriented cabs:

1. The operator must switch seat positions, depending upon travel direction, which is undesirable.

2. If the same seat position is maintained, steering the vehicle in one travel direction requires additional sensory input to supplement televised views, such as obstacle detectors, and distance-alignment sensors, and/or that an automatic or semiautomatic steering system be employed.

DISCUSSION OF CONCEPTS

Although the cross-car, end-mounted cab configuration initially appeared to present inherent, insurmountable problems, a variation of it was ultimately selected for the recommended cab-shuttle car design. The following discussion details specific ideas considered for the five general cab-shuttle car configurations, reasons for dismissing or not selecting the concepts, and the preliminary design of the selected configuration.

1. Transverse, center-driven cab: This configuration was successful on a shuttle car used in high seams (5) and initially appeared promising for thin-seam application. However, drawing the concept to scale revealed there was insufficient vertical space for it to be used in a 40-in working height. The basic problem was that the operator's feet must extend under the conveyor, using 18 in of vertical space, and the remaining space was insufficient for the conveyor and machine-to-roof clearances. The concept was eliminated on these grounds.

2. Parallel, end-driven cab: Two concepts were proposed and evaluated for this cab-shuttle car configuration: A, the operator changing seat positions

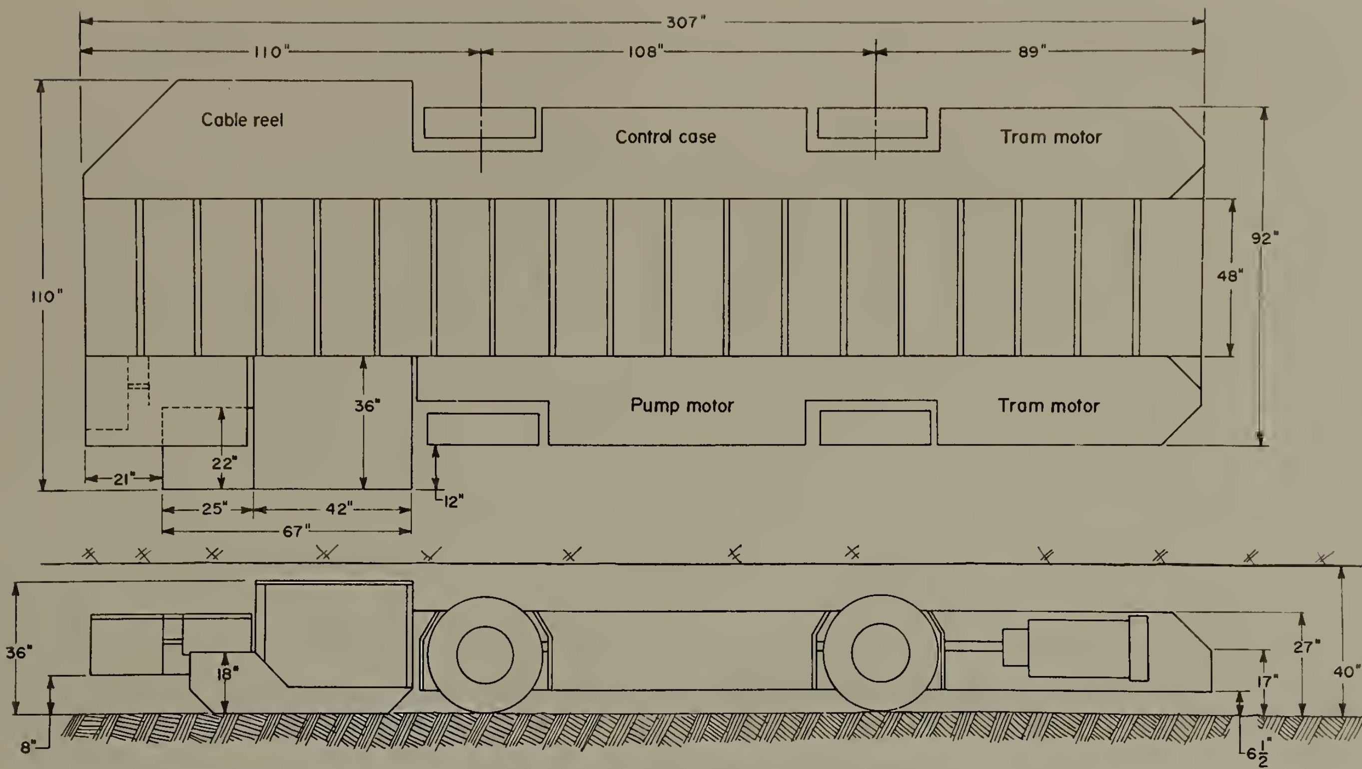


FIGURE 1.–Parallel end-driven shuttle car.

depending on travel direction (fig. 1), and B, the operator maintaining one seat position.

A. The first concept would provide the operator with very good direct vision in the travel direction away from the machine. Travel in the opposite direction would require major changes to the classical layout of shuttle car subsystems for increased direct vision and probably necessitate that CCTS's be employed to provide views to blind spots.

B. Because of the results of the remote vision experiment, the second concept would require additional sensory input supplement televised views and/or an automatic or semiautomatic steering system. As neither concept appeared particularly attractive, they were not taken beyond the discussion stage.

3. Parallel, center-driven cab: The center-driven concepts (fig. 2) did not impose length restrictions on the cab, thus providing the potential for maximum operator comfort. Two concepts on opposite ends of the technological spectrum were considered for this cab-shuttle car configuration.

A. The low-technology concept required that (1) the operator switch seat positions depending on the travel direction, (2) the cab width be approximately 10 in greater than current practice, (3) the normal layout of vehicle subsystems undergo significant changes to increase operator visibility, and (4) CCTS's be employed to improve visibility of otherwise blind areas. It was decided not to proceed with the development of this cab as it met few of the desired design criteria and did not appear applicable to a large cross section of the haulage vehicle population.

B. The high-technology cab concept included the following design features:

1. The operator would sit in one position only, regardless of travel direction, and be provided a positive indication of the current tram direction.

2. It would be a generic box, adaptable to a wide range of currently manufactured haulage vehicles.

3. An updated version of the automatic steering technology developed by the Bureau would be employed (6). This subsystem would output to a display of the vehicle's position relative to idealized paths for both straightaway tramming and the turning of crosscuts. The steering system could be placed in either manual or automatic mode.

4. Wide-angle-view CCTS's would be used, providing the operator with views of obstacles in the vehicle path.

5. Electronic rangefinder units would be placed on both ends of the vehicle and would output to a cab display the distances between the vehicle and objects in the vehicle path.

6. If possible, machine controls would be designed to be detachable from the body of the haulage vehicle. During emergency situations, this would allow remote, within-sight control.

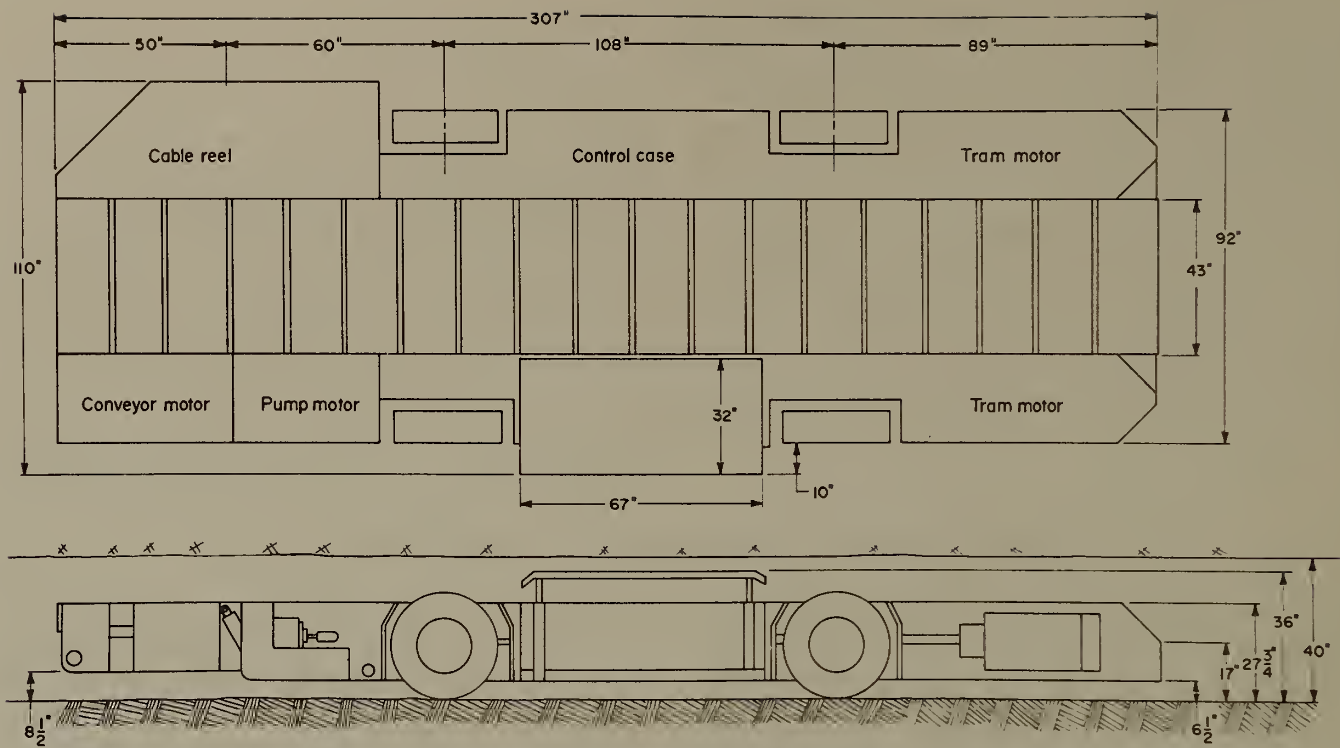


FIGURE 2.–Parallel center-driven shuttle car.

The concept met many of the desired criteria including the capability of being placed on many currently manufactured haulage vehicles or completely new designs.

Concept disadvantages included that it would be electronically complex, requiring an updated version of the automatic-steering technology, wide-angle-view CCTS's to provide the operator views of obstacles in the vehicle path, and electronic rangefinder units to indicate distances to objects. However, the main concern was the unproven ability of an operator to maneuver the machine, with no direct vision, when traveling in the direction opposite from the faced position.

It was concluded that although the high-technology concept did offer merit, it would be best pursued as a separate, future project.

4. Transverse, end-driven cab: This concept (fig. 3) worked well on higher seam vehicles because the operator was able to tram in both directions without changing seat positions. However, this configuration posed several serious problems for low-seam applications:

1. The coal-carrying capacity of the shuttle car would be decreased because the operator's legs require 18 in of space under the conveyor; and, compared to conventional design, the cab would extend an additional 10 in beyond the machine frame, requiring narrower cars for adequate maneuverability.

2. Field would be poor when tramming to the face, requiring the application of complex remote sensory input devices and CCTS's.

3. There would be the possibility of roofing and ribbing problems due to the cab position on the vehicle.

5. Cross-car, end-mounted cab: Three cab-shuttle car concepts were conceived and discussed for this configuration. The third concept was ultimately selected as the recommended concept. All the ideas positioned the cab across the end of the vehicle, with the longitudinal axis of the conveyor intersecting the operator's body and the operator's head positioned for adequate vision down the chain conveyor trough.

A. The first concept positioned the cab at the vehicle dump end, outboard of the conveyor drive structure. The coal would be discharged using a side-dump arrangement.

Advantages of the side discharge configuration included

1. The operator would have excellent, direct vision when traveling to the dump point. Because no coal would be on board, direct vision should be adequate when traveling to the face.

2. The addition of electronic subsystems, including CCTS's, could prove desirable, but would not be an absolute necessity.

3. Because of the cab location, vehicles with cabs wider than what would normally fit within the entry dimensions could be accommodated. Thus, the loss of coal-carrying capacity resulting from the installation of the side-dump mechanism could be minimized or eliminated.

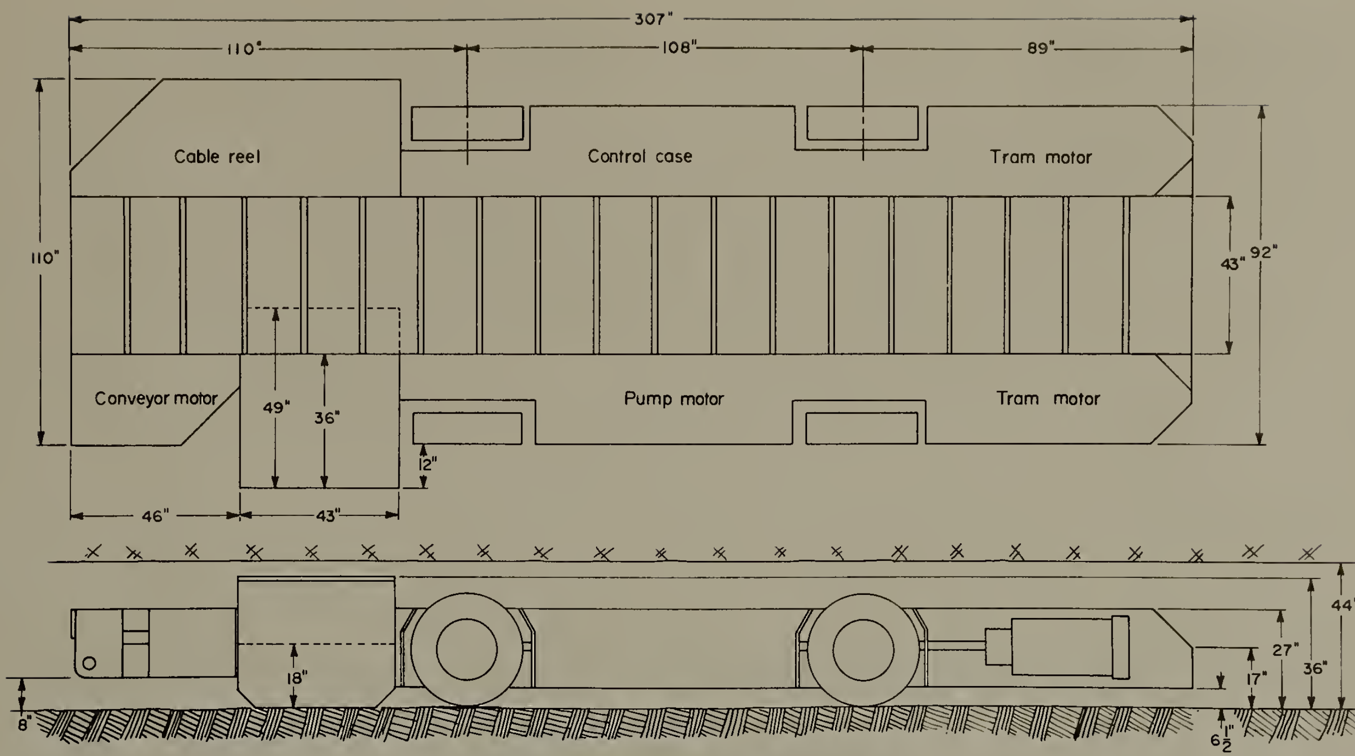


FIGURE 3.–Transverse end-driven shuttle car.

4. Completely new vehicles probably would not be required to accommodate the cabs; modification to existing vehicles might suffice.

Disadvantages identified specific to the side-discharge configuration included

1. The cab would have to be attached to the vehicle main frame by a cantilevered I-beam approximately 11 ft long and 10 in deep.

2. Because the cab would be attached to the vehicle, the ability of the cab to tolerate side loadings would be decreased.

3. A floating cab could not be utilized, resulting in a small interior space (fitting a 95th percentile male would be very difficult).

4. The side discharge would require a complex boom mechanism involving moving slides and other apparatus.

5. The overall vehicle length would increase approximately 40 in and the concept could be used only on vehicles having chain conveyors at least 56 in wide.

6. The operator could be exposed to significant amounts of dust and noise during the coal discharge process.

The disadvantages were of such magnitude that this concept was eliminated from further consideration.

B. The second concept would also position the cab across the normal boom end of the machine, but would eliminate the boom and shorten the conveyor to permit a bottom-dump arrangement. This would greatly simplify the cab mounting (fig. 4).

Specific advantages defined for the bottom discharge configuration were that

1. A semifloating cab attachment design could be employed which would provide ample interior space for a wide range of operator sizes.

2. A coal discharge boom would not be necessary, which would decrease design complexity and minimize decreased coal-carrying capacity.

3. The operator would have excellent direct vision when traveling to the dump point. Because no coal would be on board, direct vision should be adequate when traveling to the face.

4. The addition of electronic subsystems, including CCTS's, could prove desirable, but would not be an absolute necessity.

5. Because of the cab location, vehicles with cabs wider than what would normally fit within the entry dimensions could be accommodate. Thus, the loss of coal-carrying capacity, created by shortening the conveyor to accommodate the bottom discharge, could be minimized or eliminated.

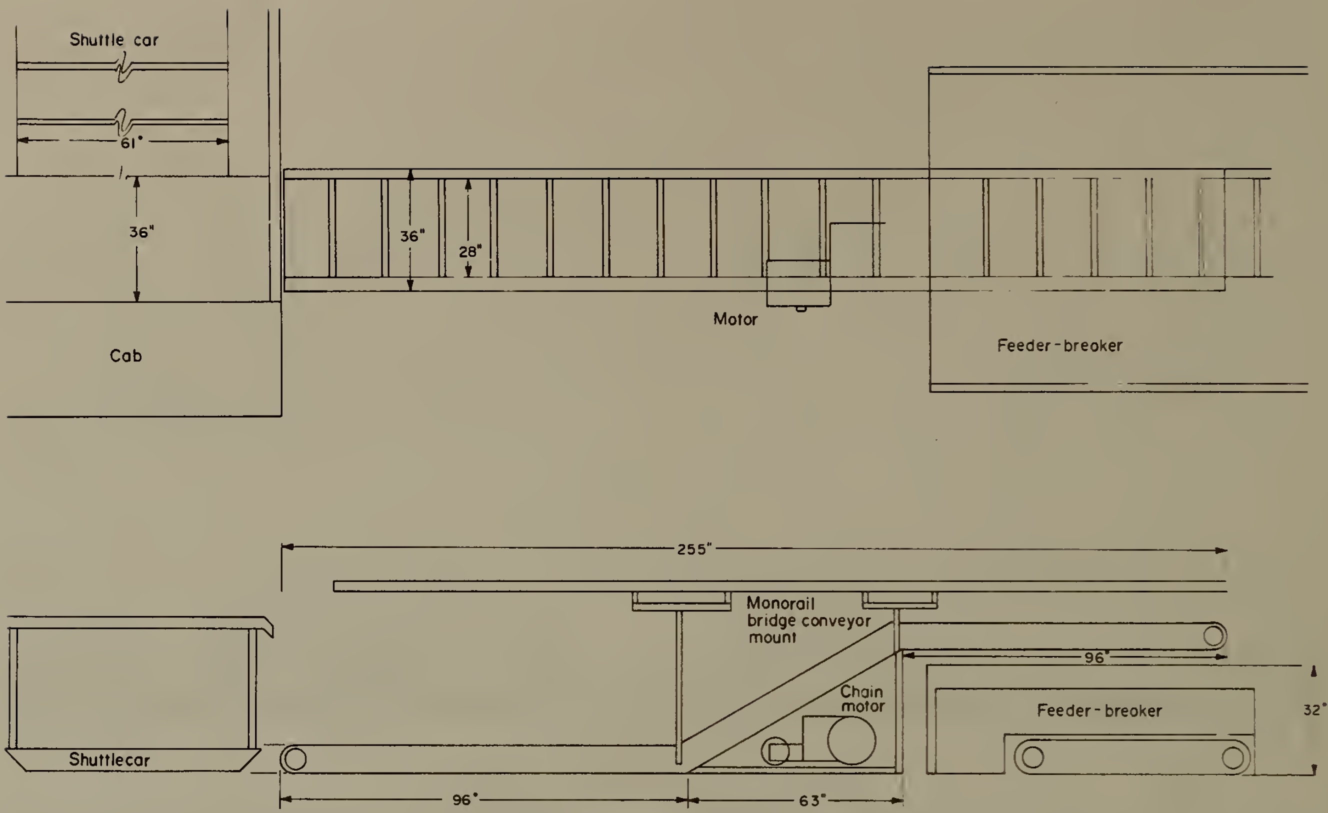


FIGURE 4.–Bottom dump shuttle car.

6. Completely new vehicles probably would not be required to accommodate the cabs; modification to existing vehicles might suffice.

Disadvantages identified specific to the bottom discharge configuration included

1. The section dump point would have to be significantly modified, either by placing the belt or feeder-breaker below ground level or requiring the vehicle to go up a ramp (taking an additional 12 in of top would be necessary).

2. The chain conveyor drive motor would have to be relocated.

3. If a ramp was not used, an additional, specialized loading machine could be required.

Disadvantages common to both the side- and bottom-discharge configurations, 5A and 5B, included

1. The overall vehicle length would increase approximately 40 in.

2. Operators could be vulnerable to injury from obstacle collisions because of the end-mounted cabs. However, the excellent direct vision provided should enable operators to avoid obstacles.

3. The concepts would be limited for use on vehicles having chain conveyors at least 56 in wide.

4. The operator could be exposed to significant amounts of dust and noise during the coal discharge process.

5. A potential problem existed in the operator being able to see the coal discharged from the miner. Assistance from the miner helper or augmented vision could be required.

At this point, the bottom discharge configuration, 5B, appeared the most attractive of all the concepts considered. It seemed capable of meeting all of the mandatory design criteria and most of the desirable criteria, including that the operator not switch seat positions depending on travel direction. The concept's primary disadvantage was that the dump point site would require extensive modifications.

As a result of a wooden mockup fabrication of the cab and preparation-evaluation of scale drawings of modified dump sites, a third concept based on the cross-car, end-mounted configuration was developed. This concept, 5C, positioned the cab across what would be the load end of a conventional shuttle car, opposite the discharge boom (fig. 5). As for the previous concepts, the operator's head was positioned to maintain good direct vision through the conveyor trough when traveling empty. The idea was to employ the same vehicle end for both coal loading and

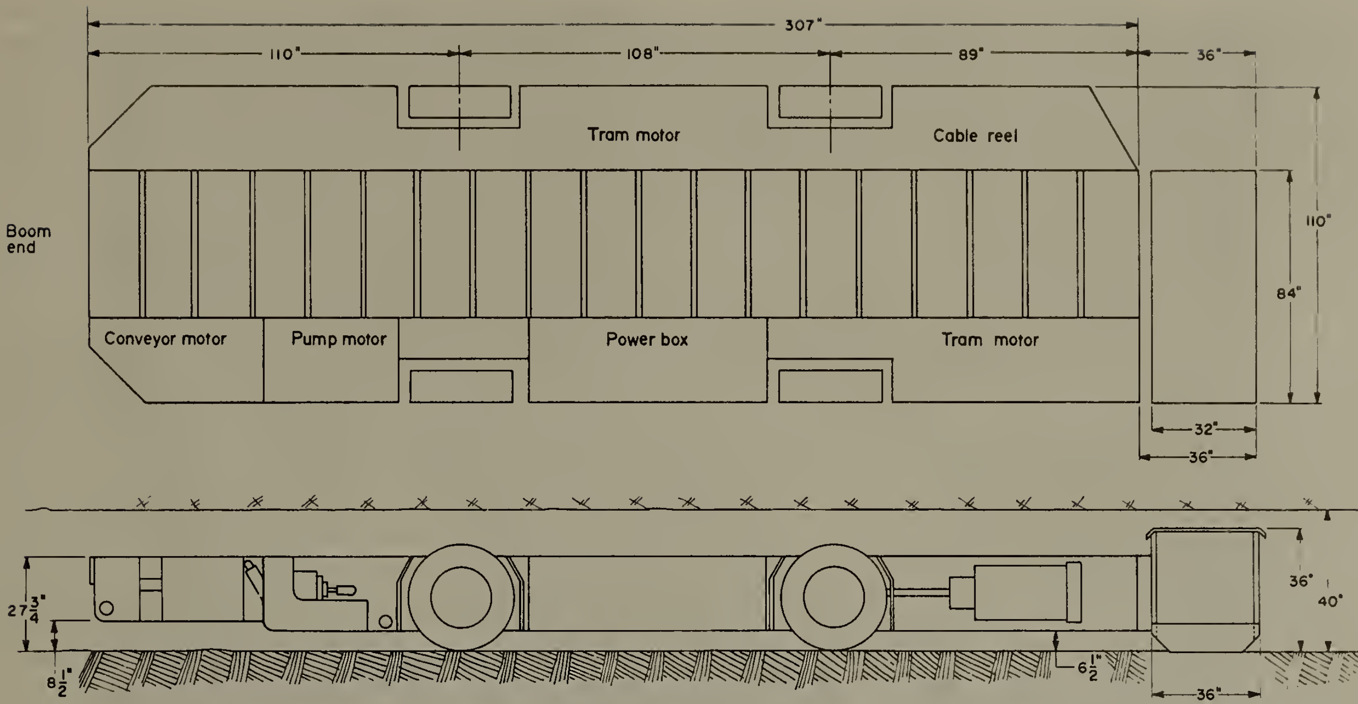


FIGURE 5.–Transversely mounted end-cab.

unloading. This concept required no major modifications to either the shuttle car or the dump site.

Previous Bureau programs had proved mockup fabrications to be valuable tools in evaluating and refining cab and canopy designs prior to full-scale fabrication. Once the cross-cab, end-mounted cab concept was determined to be feasible, detailed drawings were prepared that allowed the construction of a wooden mockup cab fabrication to be used with the bottom-discharge configuration, 5B. Because an FMC model 6L shuttle car was available and had a conveyor of sufficient width to accommodate the cab, it was used for the evaluation.

The 6L shuttle car is intended for use in working heights higher than the 40-in target height set for the cab development. Therefore, the mockup cab fabrication was sized to fit the shuttle car. However, this did not decrease the utility of the mockup in determining that the concept was feasible; it showed there was ample operator space in the cab and indicated that direct vision was even better than had been assumed.

The concept maintained all of the advantages of its predecessors and provided additional advantages.

1. A semifloating cab attachment design was employed, which provided ample interior space for a wide range of operator sizes.

2. The operator would have excellent direct vision when traveling to the dump point. Because no coal would be on board, direct vision down the empty conveyor should be adequate when traveling to the face.

3. The addition of electronic subsystems, including video monitors, proved desirable, but would not be an absolute necessity.

4. Completely new vehicles probably would not be required to accommodate the cabs; modification to existing vehicles might suffice.

5. The concept could be readily adapted to many existing shuttle cars with only limited modifications. Examples would be the National Mine Service (EIMCO) MC 28 and the FMC 5L shuttle cars.

6. Exposure to dust and noise problems during coal discharge would be eliminated.

7. No modifications to the off-loading site would be required.

8. The shuttle car could have increased coal-carrying capacity, compared with current designs, since eliminating the cab on the side of the car would permit the use of wider cars in the same size entry.

Only two potential disadvantages were identified for the concept

1. The operator would have limited direct vision for determining the size of the coal pile as the mining machine loads the car. However, tests using a mockup of the cab were conducted and showed that the direct vision could be easily augmented through the use of CCTS's.

2. The operator must turn the vehicle and then travel to the dump site with limited direct vision. This also

should not be a big problem, since the required travel distance would be very short (e.g., 15 ft).

In order to determine if these two problems could be overcome through the use of remote vision assist, a quick experiment was performed to determine the suitability of this technique. The wooden cab mockup was placed adjacent to the FMC 6L shuttle car. A video camera aimed at the front of the car was linked to a video monitor mounted inside the cab. An operator was placed inside the cab and watched the monitor as coal was loaded into the shuttle car with a conveyor (fig. 6). The operator had no trouble determining when the coal pile was high enough to be moved. From this experiment, it was determined that the concept with the auxiliary CCTS would be a workable design.

DESIGN CONSIDERATIONS

During the predesign stage of the compartment-machine development, the basic operational requirements were defined. Tasks that the machine must be able to perform were analyzed in relationship to their importance in completing a duty cycle mission. The design was considered to be a total systems program to be pursued systematically. Components were not designed in terms of their individual function but rather in terms of their impact on the entire system, which include the needs of the machine, the needs of the operator compartment, and the needs of the operator. System requirements were defined in terms of operational requirements, functions required to complete each duty cycle, performance requirements for each function, and the relationship between the equipment and operator needs.

The design requirements were broken into separate categories. The mandate of the project, to give at least equal consideration to the needs of the operator and the machine requirements, was maintained at all times throughout the design process.

The following factors were determined important for the operator to safely complete a duty cycle:

1. The primary consideration was that the operator always be protected from accidents and possible injury. The operator compartment canopy should be substantial and located to protect the operator from falls of roof and rib. Additionally, the compartment itself should be designed to prevent the operator from leaning out and being pinched or pinned between the machine frame and the roof or rib.

2. The operator should have adequate direct vision to essential elements. The major complaint about low-coal canopies is the severe restrictions they impose on operator field of view. Therefore, a serviceable design must insure optimum field of view in an environment that inherently restricts it. Operator visual requirements were broken down on a task-by-task basis. For example, during tramming, the operator must be able to ascertain the relative position of the shuttle car in the roadway, the machine velocity, and the relative location of the machine in the mine. During loading, the operator must determine the rate that coal flows from the tail boom of the miner, the relative positions of the shuttle car and the mining machine, the height of the tail boom, and the position and height of the coal load on the shuttle car. During dumping, the operator must determine the status of the dump site, the position of the machine relative to the dump site, the position of the coal load on the vehicle, and the height of the tail boom. Finally, the operator must always be able to determine the location of obstacles, hazards, and other mine personnel.

3. The control design layout must be logical and meet behavioral expectations of the operator. Control systems that are radically different from what people are used to or expect tend to induce operator error and confusion. Controls should meet the requirements outlined in Society of Automotive Engineers (SAE) XJ1314 "Human Factors Design Guidelines For Underground Mining Equipment" (table 1). These same considerations should be given to auxiliary visual displays, auditory displays, and other sensory input devices.

4. Operator comfort must be a primary consideration in order to prevent fatigue and the resulting lack of attention to the job and its inherent dangers. The operator must have adequate room so as not to be cramped and confined. This requires a wide enough compartment so the operator does not feel restrained. Additionally, as the canopy height becomes lower, the compartment must become increasingly longer to accommodate the operator.

5. The operator seat must provide operator comfort and prevent fatigue. Most original equipment manufacturer low-coal shuttle car seating is inadequate. proper seating should be padded and equipped with an adjustable back (with lumbar support) and an adjustable head rest. Specific requirements are that 5th percentile female through 95th percentile male operators see over the top of the machine frame, and, the seat width be adequate for the 95th percentile male (fig. 7).

6. The compartment design should not impede operator ingress and egress. Openings must be free of obstacles that may snag the operator's belt, cap-lamp battery, and self-rescuer. Two important design features can be employed to aid the operator. One is to use as many handrails and handholds as are feasible to facilitate quick and smooth ingress-egress. Another important design consideration involves alternative exits. There are situations when the operator must exit in a hurry (e.g., roof falls, fire, inundation, etc.). If the main egress route from the machine is blocked, there should be an alternative way out. This alternative escape opening should measure, at a minimum, 18 by 30 in.

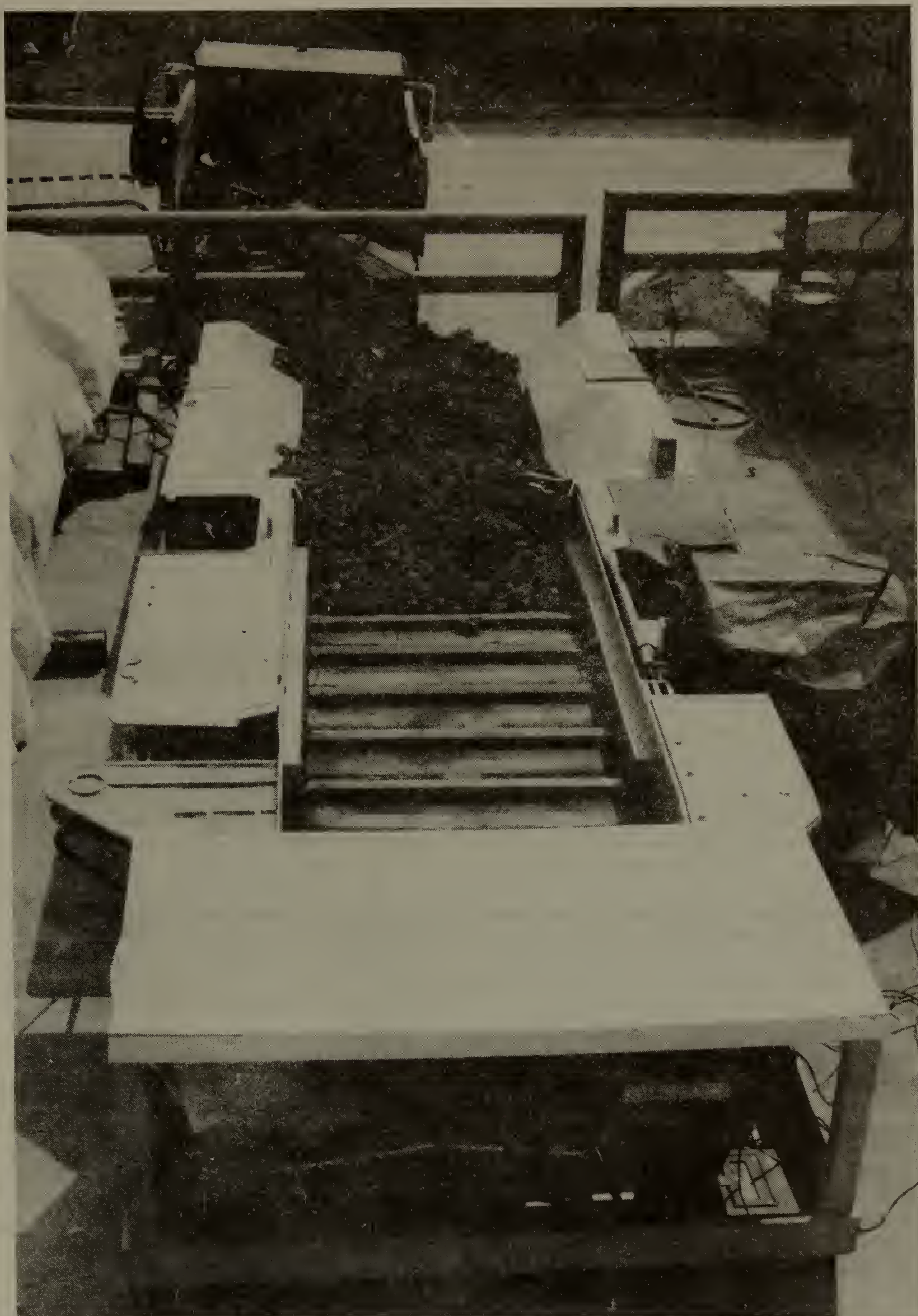


FIGURE 6.–Vision-assist test.

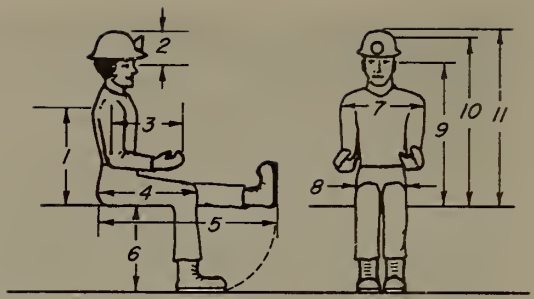
TABLE 1.–Recommended control motions

Control device	Motion and response
Foot pedals	Push to– Activate. Accelerate (forward). Apply brakes. Turn on or off. Engage a function. Release to– Deactivate. Decelerate. Release. Disengage.
Levers	Push to– Move forward. Increase. Lower. Activate. Pull to– Stop. Move backwards. Brake. Raise.
Pushbuttons	Push to engage-disengage.
Rotary switches	Turn clockwise to increase.
Toggle switches	Push up to– Select a function. Activate. Push down to deactivate.
Emergency cutoff	Push to deactivate.
Cranks or wheels	Turn (clockwise) to– Start. Increase speed. Turn right.

7. Where necessary, auxiliary sensory inputs to the operator should be provided. Because of the extremely confined space in a low-coal operator compartment, it is highly unlikely that an operator can directly perceive all of the information desired to safely control the vehicle operation. For maximum efficiency, the operator should have direct vision to as many important visual attention locations as possible. Auxiliary sensory inputs should provide the operator information on blind spots that cannot be directly viewed or otherwise perceived.

8. The operator compartment-shuttle car must be designed for the extremes rather than the average operator. Efficient operation requires that each operator be perfectly positioned, allowing performance of the required tasks with a minimum of stress. To accommodate the majority of users, a good design provides adequate space for a comfortable operating position and places controls within easy reach for a 6-ft 3-in male dressed in mining clothes with hardhat, cap lamp, and self-rescuer.

The requirements for the machine to successfully complete its mission duty cycle require equal consideration. Any design would be useless if the primary function of the machine could not be efficiently accomplished.



		Dimensions, in	
		5th-percentile female	95th-percentile male
1	Shoulder height	19.7	25.7
2	Eye-to-helmet top	6.0	6.5
3	Forearm-hand length	15.3	20.2
4	Buttock-knee length	20.5	25.9
5	Buttock-leg length	38.0	46.1
6	Back-of-knee height	14.8	18.2
7	Shoulder breadth	14.1	20.1
8	Hip breadth	12.9	15.4
9	Eye height	26.9	33.9
10	Sitting height	30.9	38.4
11	Sitting height with helmet	32.9	40.4

FIGURE 7.–Coal miner anthropometrics.

1. The first limitation is the design criteria that the cab-machine operate in a 40-in working height coal seam. Although previous studies showed that a significant number of shuttle cars operate in coal seams between 42 and 48 in without canopies, due to court-obtained variances, the advisory committee decided the project goal should be set below the cutoff point of 42 in set forth in 30 CFR 75.1710. Based on this, a target goal of 40 in was set. It was felt that a successful compartment-shuttle car design for this seam height would be a significant accomplishment and could be approached with a reasonable degree of confidence.

2. The concept should be adaptable, with minimal modifications, to as many existing shuttle cars as possible. It is realized that to achieve the project goals the final design will have to depart from traditional design concepts and practices; historically, no one has been able to resolve this issue since shuttle cars were introduced into the mining industry in the 1930's. However, use of as much of the currently available base vehicles as possible will reduce costs and increase acceptance in the mining community.

3. No mining system equipment modifications should be required to accommodate the new equipment. Several designs were considered that would have necessitated

extensive modifications to the dump sites and tail boom of the miner. However, these would have significantly increased the cost of the system and hindered acceptance.

4. The addition of the cab should cause no decrease in coal-carrying capacity. The primary mission of a shuttle car is to rapidly carry as much coal as possible from the mining machine to the dump site. Time studies have shown that haulage is the biggest bottleneck in the production cycle; a bigger bottleneck would not help a new system gain acceptance.

5. Adequate tram clearance must be provided for the shuttle car to efficiently complete its mission. Vehicles must be able to achieve maximum operating velocities without "ribbing" or "roofing" (striking the ribs or roof) to maximize production, maintain a stable workflow, and permit safe and efficient operation.

DESIGN PROCEDURE

The design concept chosen was a cross-car, end-mounted configuration that positioned the cab across what would be the load end of a conventional shuttle car, opposite the discharge boom. The operator is positioned across the end of the vehicle, perpendicular to the longitudinal axis of the chain conveyor. This arrangement would give the operator unobstructed vision when tramming to the dump site and very good direct vision down the empty conveyor when tramming to the face. The main disadvantage appeared to be increased complexity of procedures when unloading coal. The idea was to employ the boom end of the vehicle for both coal loading and unloading. This would require the operator to back up a short distance to the dump site with his or her direct vision obstructed by the coal pile.

The specific design procedures were followed in accordance with the experience the Bureau has developed in cab design in over a decade of work in this area. The transversely mounted, end-cab (TMEC) concept selected for further development was analyzed to insure that it would meet the previously established performance criteria. A technical description of the proposed shuttle car cab concept was sent to major U.S. shuttle car manufacturers to solicit their comments. The responses received were very favorable and encouraging.

The TMEC concept needed to be refined and finalized to better adapt it to existing low-coal shuttle cars. The first task was to finalize the design of the basic compartment structure (fig. 8). The optimal compartment

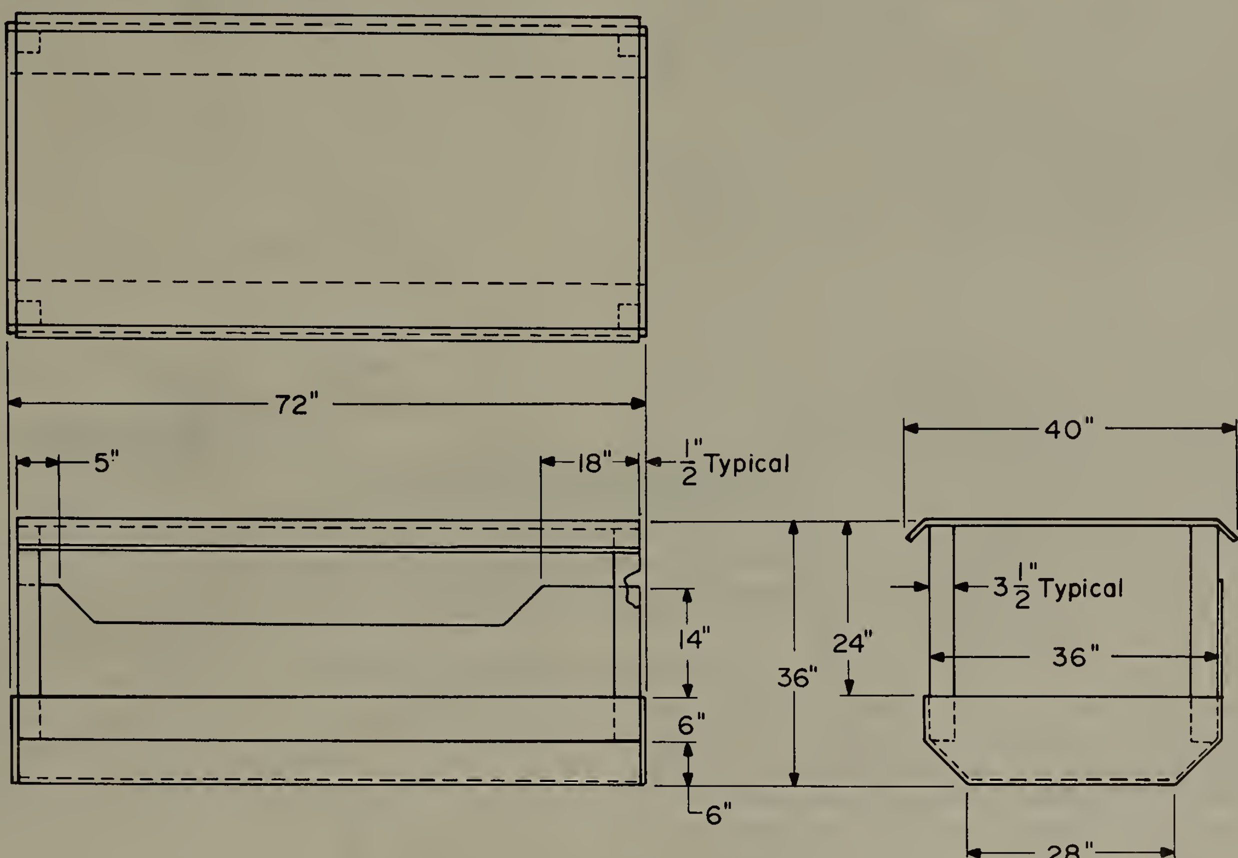


FIGURE 8.–Compartment design.

dimensions were determined to be 36 in wide by 72 in long by 36 in high.

The 36-in width provides an operator with sufficient hip room and freedom of movement. This width should not interfere with the capability of the shuttle car to tram around corners; it is the approximate dimension the unused load end of the vehicle can be shortened without altering the stock chain conveyor or decreasing haulage capacity. The 72-in compartment length provides the operator with extra leg room for comfort in a reclined seating position. The 36-in canopy height should provide ample clearance to prevent roofing in a 40-in coal seam, since the operator compartment is designed to be a full-floating cab. Canopy support posts were placed as far outboard on the operator compartment as possible, so as not to interfere with operator field of vision. Finally, all corners and edges of the operator compartment and canopy were beveled or sloped so the compartment could float over or deflect, rather than jam on any roadway obstacles.

Several additional modifications necessary to adapt the concept to existing shuttle cars were identified. First, the cable reel will have to be moved from the boom end to the cab end of the vehicle to prevent running over the trailing cable. The boom end of the vehicle will need additional reinforcement, since it is now used for both loading and dumping. Finally, the cab end of the shuttle car will need to be shortened 36 in to facilitate tramming around corners. None of these modifications should affect operation or decrease coal-carrying capacity, since wider shuttle cars can be used in the same width entries with the operator cab relocated from the side of the car.

Design details of the compartment and related components (seating and controls) were evaluated using several of the Bureau's computer modeling programs.

The first program used was the crew-station assessment of reach (CAR) program; it insured that all the shuttle car controls are at optimum reach locations. Numerous control layouts (fig. 9) were designed and analyzed. These layouts placed the controls within easy reach of all 5th to 95th percentile operators without interfering with required vision. All of the selected controls are small electrical units that activate relay-controlled solenoids. This use results in considerable space savings within the cab as compared with employing conventional, bulky, hydraulic valves and associated hoses. The control layout selected, after the computer analysis, is shown in figure 10. This design provides a control panel that is positioned in front of and within easy reach of the operator. It swings out of the way to provide easy ingress and egress.

The second program was the "CAP" crew-station analysis program (CAP), which analyzed the anthropometric parameters of the cab and checked operator vision at predetermined-required visual attention locations. This program generates a simulation of the operator field of vision from within the shuttle car to predetermined vision points (fig. 11). These points are then weighted and compared to a list of required visual attention locations established from previous Bureau

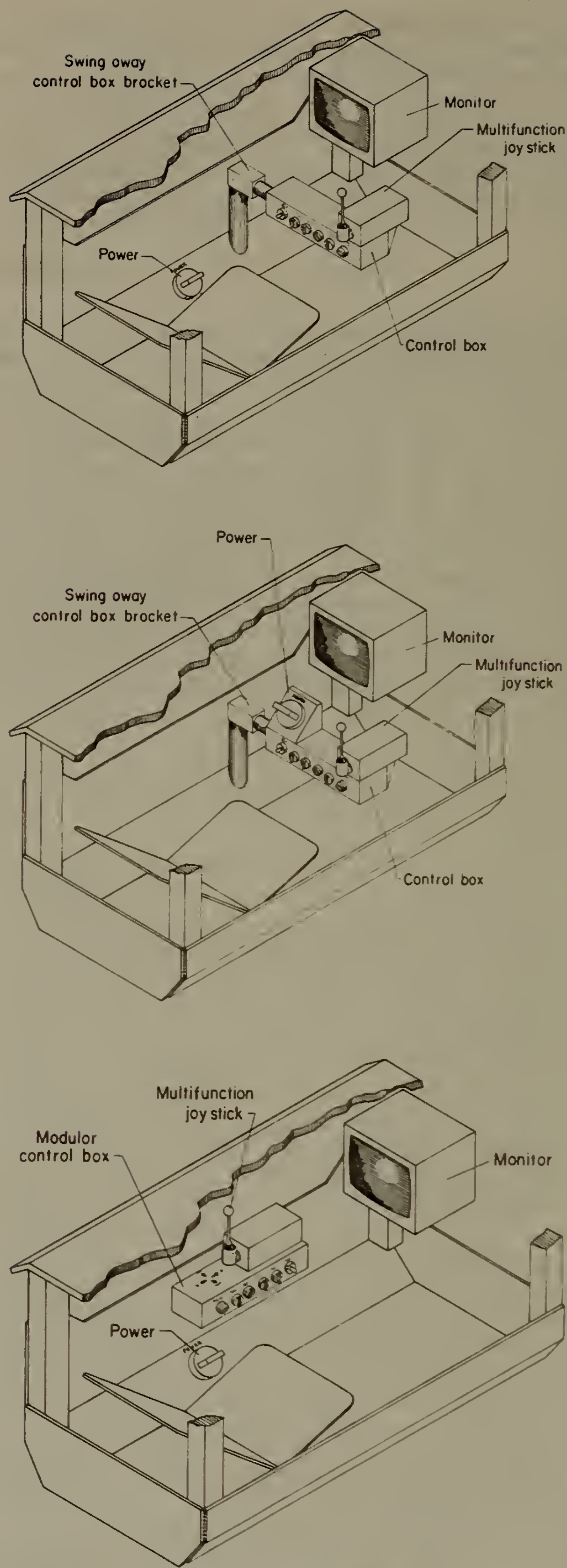


FIGURE 9.–Control layouts.

programs. The TMEC provided field of vision superior to even the operator compartments without canopies now in use in low-coal seams.

The next component to be designed was the seat for the shuttle car operator. Because of the limited confines of low coal, the operator must be as comfortable as possible in order to effectively perform for an 8-h or longer shift. After careful consideration, a seat designed under a previous Bureau project was selected. This seat (fig. 12) permits the operator to sit in the required reclined position. Important features include lumbar support and an adjustable back to permit smaller operators to sit in a more upright position. The seat pad is 15 in long, 22 in wide and has an adjustable tilt. It is short enough to prevent cutting off circulation in the legs and wide enough to provide adequate hip room. Another important feature is an adjustable, preshaped support; it holds the head and neck in a comfortable, upright position, allowing protracted periods of operation. The entire seat is contoured to hold the operator securely, formed of foam padding covered with vinyl fabric. An option under consideration is a seat belt with a Velcro hook-and-loop fastener, a rigid locking belt is not needed but a lightweight, easily fastened belt using a Velcro hook-and-loop fastener would help secure the operator in the seat when tramming over rough bottom.

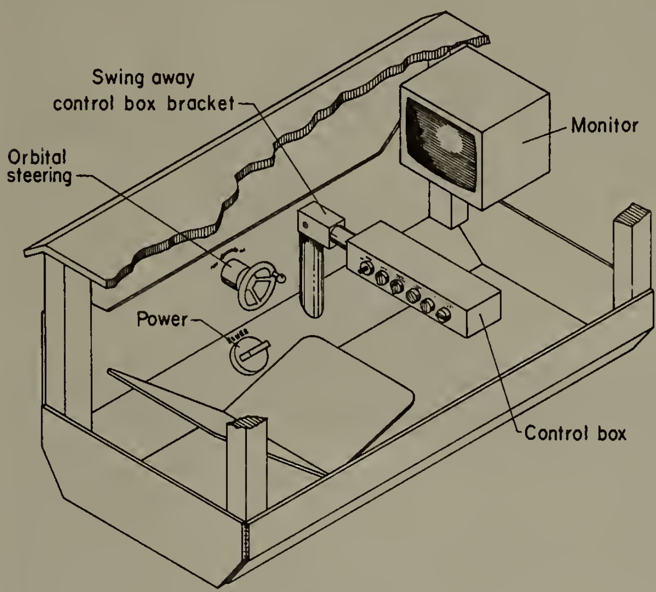


FIGURE 10.–Selected control layout.

Previous testing had determined that auxiliary vision assist would be necessary. The final design employs the most favorable and cost-effective solution–it allows the operator direct vision to as many of the required visual attention locations as possible. Direct vision is supplemented by providing visual input at the blind spots through the use of a simple CCTS. The CCTS provides visual assistance for those reference points where the operator requires additional information. The system provides an overlap of direct and transmitted vision so that (1) the operator is given a point of reference between direct view of an object and the view of the same object on the monitor, and (2) the operator is given a choice, where possible, between the direct and transmitted view of objects.

The final system consisted of one closed-circuit camera enclosed in a protective, explosion-proof housing mounted on the boom end of the shuttle car, and, one black-and-white monitor located inside the operator compartment. It was determined that only two areas required vision assistance: a view of the coal flowing from the boom of the continuous miner and a view of the dump site when backing to it. Therefore, a two-position rotary actuator was selected to pan the camera 90°; no camera tilt was deemed necessary.

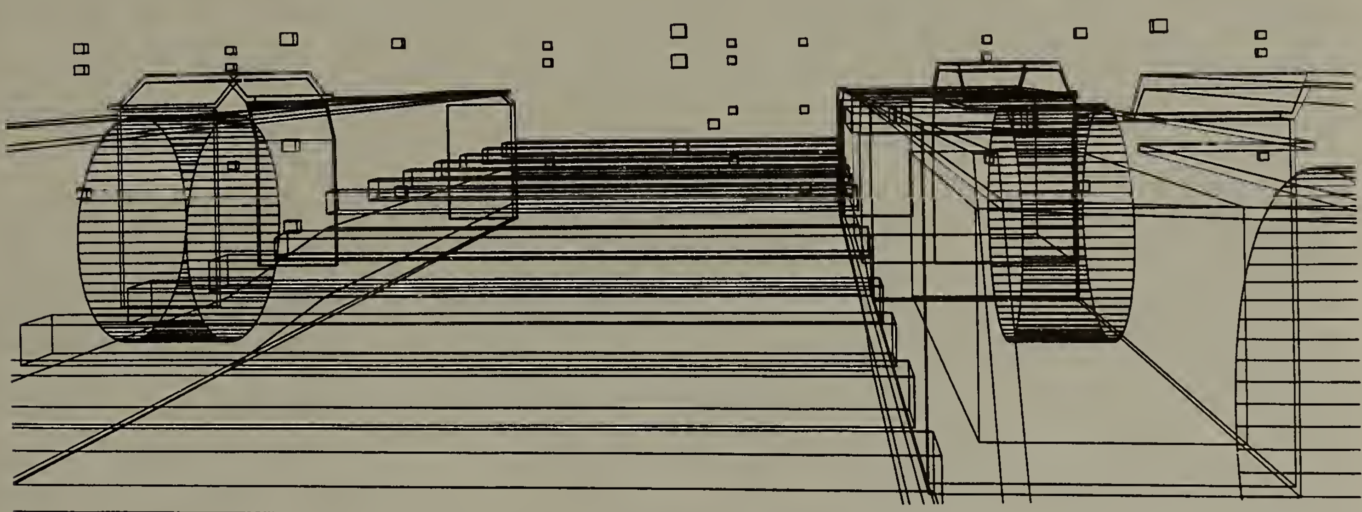


FIGURE 11.–Computer-generated field of vision.

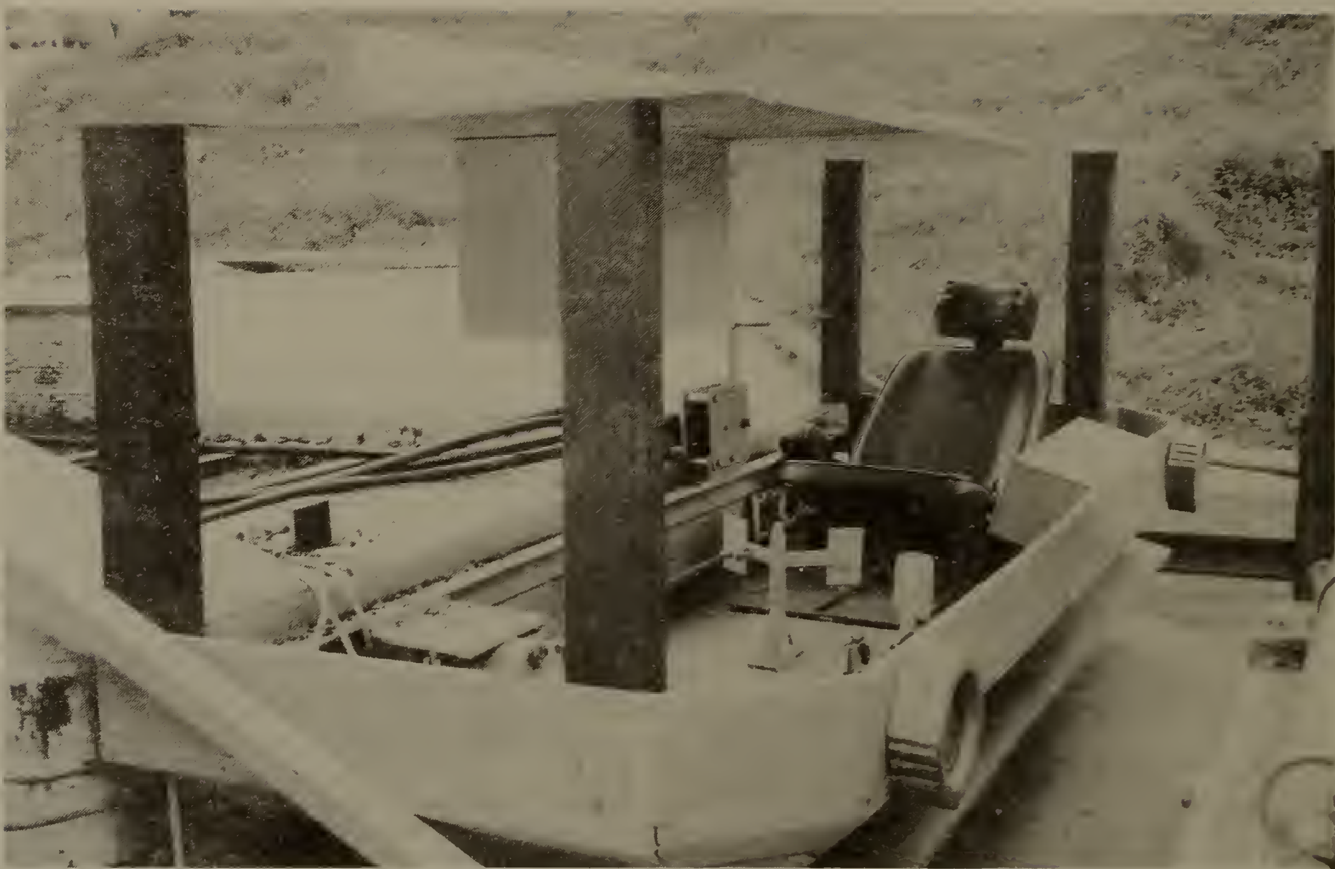


FIGURE 12.–Shuttle car operator seat.

MOCKUP AND EVALUATION

The mockup and evaluation of a proposed operator compartment, prior to the construction of a full-scale prototype, has proven to be a useful tool in refining design deficiencies and allowing improvements at an early stage of the project development. It was decided that, to accurately evaluate the proposed operator compartment-shuttle car concept, a semifunctional mockup needed to be constructed. The completely unique position of the operator compartment, with respect to the shuttle car, posed a question as to whether or not an operator could effectively control the machine from the cross-car position.

To construct the working mockup, a steel platform was welded to the end of a functioning MC36 shuttle car. This served as a base on which to construct the compartment mockup. The available shuttle car was not a low-coal shuttle car, having a 36-in frame height. Therefore, the base plate was positioned 16 in above the ground to simulate the spatial and visual conditions the operator would perceive when the compartment was installed on a shuttle car with a 28-in frame height. The previously selected control system layout was installed along with the selected operator seat and the CCTS. Fully functional steering, brake, and tram controls were employed so that the actual feel of driving the shuttle car could be evaluated.

Once the mockup was completed and all systems were functioning, a surface evaluation of the system was conducted. Several experienced operators trammed the shuttle car through a predetermined course; equipment performance and operator comments were noted. The operator compartment was then evaluated based on the previously established project criteria.

The overall results of the evaluation were encouraging. After a brief practice period to orient themselves to the new system, the operators were able to maneuver the shuttle car through the course with comparative ease. Operator comments primarily centered on a dramatic increase in field of vision and space when comparing the new design to traditional shuttle car operator compartments. Operator ingress-egress was accomplished with relative ease, and the seating was easily adjusted to accommodate all operators. In general, the proposed operator compartment-shuttle car concept appeared to be a feasible and efficient solution to the difficult problem of providing protection for thin-seam shuttle car operators.

CHANGES RESULTING FROM MOCKUP

Although primarily successful, the evaluation identified several improvements that should be incorporated in the control layout. These improvements were to better accommodate a 95th percentile male operator. The swing-away control panel located in front of the operator enhanced ingress-egress for most operators, but tended to hit the legs of very large operators. Therefore, the decision was made to place the operator controls in a more traditional location on the side of the operator compartment. This arrangement does not provide the same ease of reach to the controls, but is satisfactory and does permit the accommodation of a greater segment of the operator population.

The second improvement was to modify the standard, orbital steering unit used to maneuver the shuttle car. Previous experience with the anthropometric design of steering units had shown that positive directional steering (where the shuttle car turns right when the wheel is turned clockwise and left when the wheel is turned counterclockwise) is the most desirable design philosophy. However, for some operators, it did not always function as expected for this unique situation. The design does not require the operator to change seating positions according to the direction of travel. Based on learned behavior from driving an automobile, an operator's performance expectation could be that the steering direction would be opposite when traveling in the opposing directions. Since this was a problem for some operators, it was assumed that changing the steering to a nonpositive pattern could cause problems for the operators that had adjusted to the original system. The solution was to convert the standard orbital steering, through the use of a gearing mechanism, into a joystick-type steering (fig. 13). This new system steers the car to the right whenever the joystick is pushed to the right and vice versa regardless of tram direction.

Once these modifications were incorporated into the compartment mockup (fig. 14), the evaluation trials were repeated. Since the new steering system had no conceptional relationship with an automobile, all operators readily adapted to the redesigned steering and were easily able to maneuver the shuttle car in either tram direction. The second set of trials went smoothly with no perceivable major problems remaining. The compartment design now appears ready for full-scale fabrication and test of proof-of-concept.

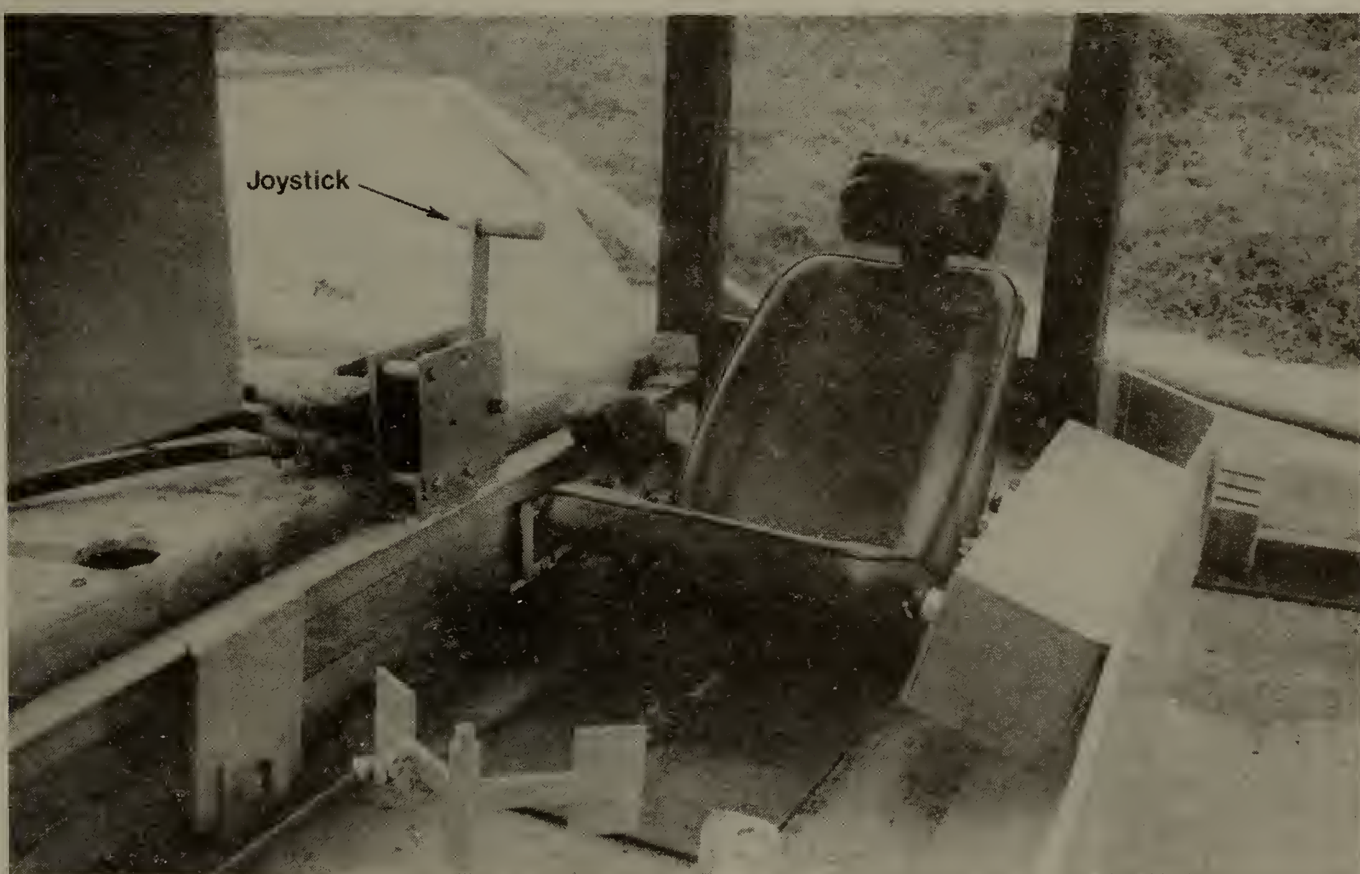


FIGURE 13.–Joystick steering.

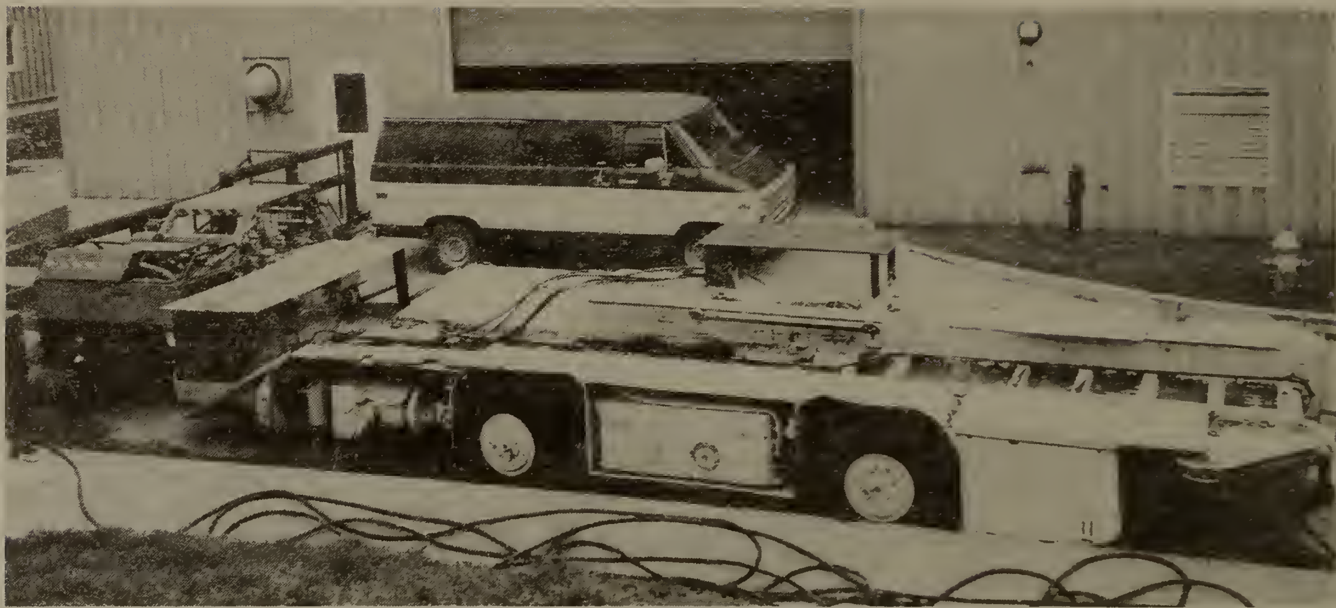


FIGURE 14.–Final mockup.

CONCLUSIONS

From the work completed, it appears that the Bureau of Mines TMEC concept for a operator compartment-shuttle car is a feasible and safer solution to the problem of implementing protective operator structures on low-coal shuttle cars used in 40-in working heights. The developed concept provides good operator protection from the hazards of roof falls and eliminates the possibility of pinching-squeezing accidents (responsible for 90 pct of all shuttle car accidents). The concept overcomes the primary objection to canopies – the lack of direct vision. Its unique location on the shuttle car takes advantage of the empty conveyor to provide the operator with a direct line of sight to the vast majority of required visual attention locations. The design also provides the operator with ample space for comfort. Additionally, this concept meets all of the design criteria established by the project advisory committee.

It is anticipated that the project will continue through the fabrication of a full-scale prototype for proof-of-concept underground evaluation. Future work will include the fabrication of a generic compartment that can be adapted to an existing shuttle car and the detailed specifications for a shuttle car incorporating the concept.

Specific tasks should include fabrication of a generic compartment and all related hardware. A compartment should be constructed that can be adapted to a modified low-coal shuttle car when one becomes available. All of the control systems and hydraulic modifications should be constructed and tested on a currently available high-coal shuttle car to verify correct function and suitability.

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